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Effects of Different Sources of Fertilizer Nitrogen on Growth and Nutrition of Western Hemlock Seedlings

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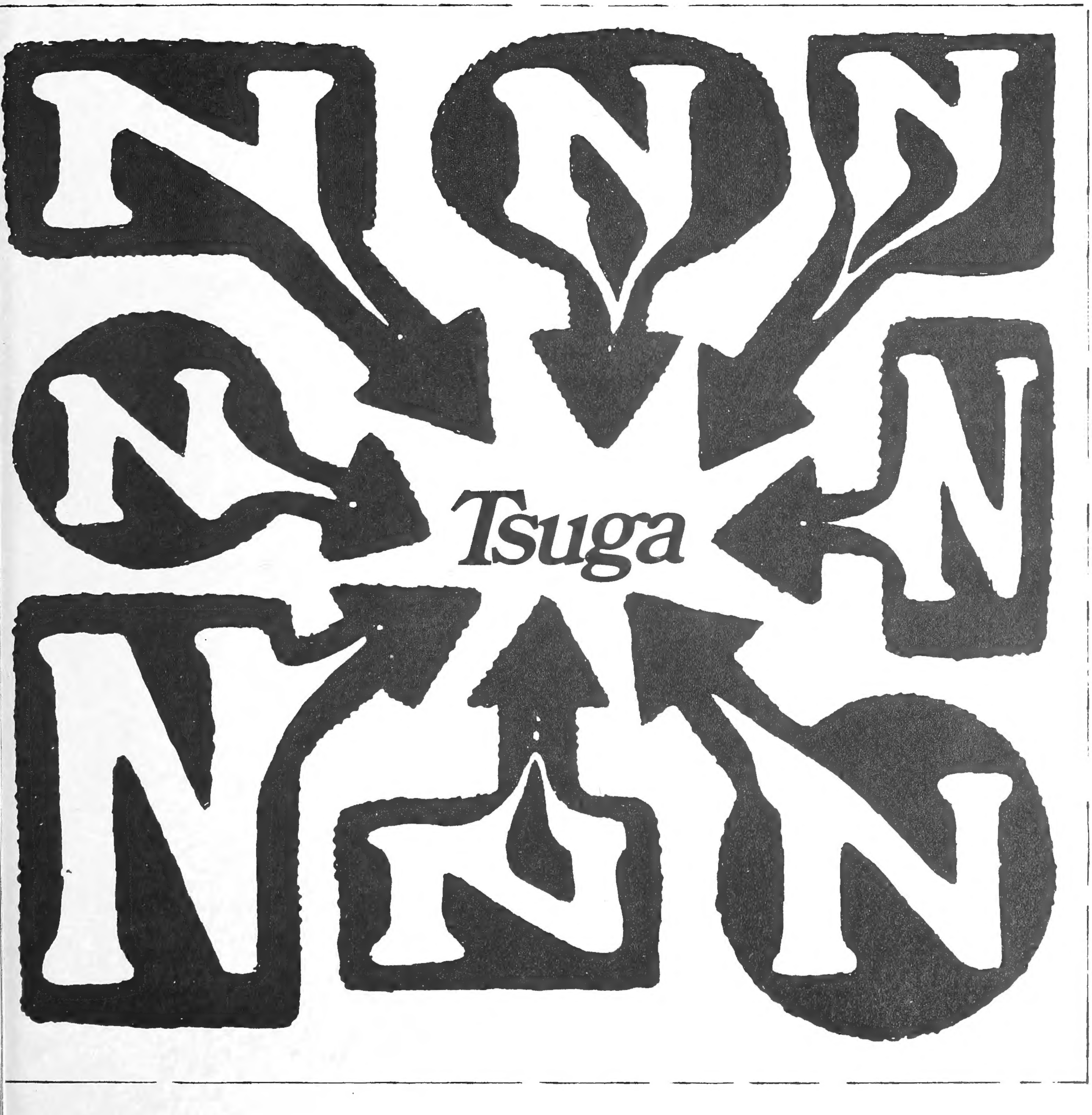

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English Equivalents

1 liter = 0.2642 gallon
1 kilogram = 2.2046 pound
1 gram = 0.0353 ounce
1 centimeter = 0.3937 inch
1 kilogram per hectare = 1.1206 pounds per acre
$(9/5^{\circ}C) + 32 = {}^{\circ}F$

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EFFECTS OF DIFFERENT SOURCES OF FERTILIZER NITROGEN ON GROWTH AND NUTRITION OF WESTERN HEMLOCK

Reference Abstract

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1980. Effects of different sources of fertilizer nitrogen on growth and nutrition of western hemlock seedlings. USDA For. Serv. Res. Pap. PNW-267, 15 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Twelve different nitrogen (N) fertilizer treatments were tested on potted western hemlock (Tsuga heterophylla (Raf.) Sarg.) seedlings. Fertilizers affected soil N and pH, and growth and foliar chemical composition of seedlings. Urea plus N-Serve and sulfur-coated urea appear more promising for promoting growth than other fertilizers tested. Results, however, do not explain reported variability in response of hemlock stands to N fertilization.

Keywords: Nitrogen fertilizer response, seedling growth, western hemlock, Tsuga heterophylla.

RESEARCH SUMMARY

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The following fertilization treatments were applied in the spring to potted, 4-year-old western hemlock (Tsuga heterophylla (Raf.) Sarg.) seedlings: untreated control, ammonium nitrate, ammonium sulfate, ammonium sulfate plus N-Serve, ammonium sulfate plus calcium sulfate, calcium nitrate, sulfur-coated urea, urea, urea plus N-Serve, urea-ammonium sulfate, urea plus calcium sulfate, urea-gypsum, urea-ammonium polyphosphate. Application rates were equivalent to 224 and 448 kilograms of nitrogen (N) per hectare, and seedlings were harvested 3 and 8 months after treatment. Soil pH varied by treatment, and most urea fertilizers caused a substantial initial rise. Fertilizers were nitrified in the soil, and N-Serve was an effective nitrification inhibitor. Seedling growth was considerably more with fertilizer than without, but most differences between fertilized and unfertilized seedlings were not significant; differences between treatments were small, although urea plus N-Serve and sulfur-coated urea appear more promising. Fertilization greatly increased the level of chlorophyll and more than doubled total N content in the foliage. Foliage from the different fertilization treatments contained similar levels of total N, and

concentrations of the soluble N fractions were always small. Total N in foliage was significantly correlated with nitrate N of the soil and with total chlorophyll. Moreover, foliar concentrations of the macroelements and microelements determined were, in general, either depressed or unaffected by fertilizer. Results suggest that the source of N does not account for reported variability in response of natural stands of western hemlock to N fertilization, although field tests with some N sources are warranted.

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INTRODUCTION

Growth responses of natural stands of western hemlock (Tsuga heterophylla (Raf.) Sarg.) to nitrogen (N) fertilization have been extremely variable. Responses reported so far range from increases of 50 percent or more to apparent reductions of about 20 percent. Generally, N fertilization has been more successful in stands located on the lowlands west of Puget Sound and on the west slopes of the Cascade Range than in forests of coastal Oregon and Washington where N fertilization is now believed unprofitable (DeBell et al. 1975, Webster et al. 1976).

Many factors may be responsible for variation in response of trees to N fertilization. The form of N applied may be a significant factor; it has been known to affect both growth and chemical composition of conifers other than western hemlock (Pharis et al. 1964, McFee and Stone 1968, Radwan et al. 1971, Christersson 1972, Van den Driessche and Dangerfield 1975).

Information on effects of N sources on western hemlock is very limited and generally suggests that the species favors ammonium nitrogen (Taylor 1935, Swan 1960, Krajina et al. 1973) or a mixture of ammonium and nitrate nitrogen (Van den Driessche 1971, Krajina et al. 1973). This information does not explain causes of variation in response under field conditions to ammonium fertilizers or to urea which is very rapidly hydrolyzed to ammonium carbonate in most soils. Furthermore, the literature contains no data on effects of the different formulations of urea or nitrification inhibitors.

In this study, we evaluated 12 fertilizer treatments on western hemlock seedlings potted in uniform, light soil. We applied the test treatments at two rates and determined effects of the fertilizers on soil and seedlings.

MATERIALS AND METHODS

Test seedlings.--In February 1976, 2-1 western hemlock seedlings from a low elevation Washington seed source were individually potted in 7.6-liter plastic pots. Each pot contained about 6 kg of Tumwater sandy loam soil, and the seedlings were allowed to get established in the pots through the 1976 growing season. In March 1977, 1 month before treatment, seedlings were watered with half-strength Hoagland's nutrient solution lacking N (Hoagland and Arnon 1950). In April 1977, the height and diameter of the seedlings were measured prior to treatment. Seedlings were then numbered and assigned at random to receive the different treatments. There were 10 pots per treatment: two for measurements of pH, four for a seedling harvest in August 1977, and four for a final harvest in January 1978. Seedlings were kept under a shaded, roofed shelter to avoid leaching of fertilizer by rain.

Fertilization treatments.--There were 12 fertilization treatments and an unfertilized control:

1. Ammonium nitrate, commercial fertilizer, 34 percent N.
2. Ammonium sulfate, commercial fertilizer, 21 percent N, 24 percent sulfur (S).
3. Ammonium sulfate (same as No. 2) plus N-Serve.[1/]
4. Ammonium sulfate (same as No. 2) plus calcium sulfate.[2/]
5. Calcium nitrate, commercial fertilizer, 15.5 percent N, 22 percent calcium (Ca).
6. Sulfur-coated urea, from Tennessee Valley Authority (TVA), Alabama, 35.9 percent N, 17.5 percent S.
7. Urea, commercial fertilizer, 46 percent N.
8. Urea (same as No. 7) plus N-Serve.
9. Urea-ammonium sulfate, from TVA, Alabama, 40.8 percent N, 4.5 percent S.
10. Urea (same as No. 7) plus calcium sulfate.
11. Urea-gypsum, from Union Oil Company, California, 34 percent N, 10 percent S.
12. Urea-ammonium polyphosphate, from TVA, Alabama, 35 percent N, 17.8 percent P_2O_5.

Treatments were applied at two rates equivalent to 224 and 448 kg N/ha. N-Serve was mixed with the fertilizer before application at rates of 1.12 and 2.24 kg/ha for the low- and high-rate treatments. Fertilizers were mixed with the top 2 cm of soil, and pots were watered the same day. Treatments were applied April 22, 1977; throughout the 1977 growing season, seedlings were watered as needed without wetting the foliage or leaching of soil solution.

Soil pH measurements.--Two pots of each treatment were used to determine pH during the first 2 months after fertilizer application. Soil was obtained from the pots with a sampling tube to a depth of 7.6 cm after removal of visible undissolved fertilizer from the surface and with minimum disturbance to the seedlings. Determinations were made on May 2, May 12, and June 30, 1977; soils were returned to their respective pots after measurement. Soil for two additional measurements of pH were obtained from the other pots used for the first (August 1, 1977) and second (January 3, 1978) seedling harvests, after seedlings were lifted and soils were composited as outlined below. On the five sampling dates, soil was thoroughly mixed with distilled water (1:1) and pH was measured with glass electrode after the suspension had been stirred with a magnetic stirrer for 15 minutes.

[1/] A nitrification inhibitor produced by the Dow Chemical Company. Active ingredient is 2-chloro-6-(trichloromethyl)pyridine. Mention of companies and products does not constitute an endorsement by the U.S. Department of Agriculture.

[2/] $CaSO_4.2H_2O$ added in amounts containing Ca equivalent to that in the calcium nitrate treatment.

Growth measurements.--For the first harvest, four pots were chosen at random from the eight pots not used for the first three pH measurements. The remaining four pots were used for the second harvest. In each case, height and diameter of the seedlings were determined. Representative samples of current year's needles were taken from the seedlings for chemical analysis as outlined below. Seedlings were then lifted and severed at the root collar. Shoots were dried at 65°C to constant weight in a forced-air oven. Dry weights of needles taken for chemical analysis were added to weights of the corresponding seedling shoots to obtain dry weight of shoots.

Sampling and processing of foliage.--Sampling was limited to fully expanded current year's needles. Ten-gram fresh needle samples were taken from each seedling. Needles were obtained from all parts of the seedlings, and samples of each two seedlings of each treatment were pooled to produce composite samples of 20 g. There were two composite samples per treatment in each harvest. From these samples, fresh subsamples were taken to determine moisture, chlorophyll, and some nitrogen fractions. Remaining tissue was dried to constant weight at 65°C, ground to 40 mesh in a Wiley mill, and stored in sealed containers at -15°C until needed for determination of total N in the first harvest, and estimation of total N, phosphorus (P), potassium (K), Ca, magnesium (Mg), S, manganese (Mn), iron (Fe), zinc (Zn), and copper (Cu), in the second harvest.

Soil sampling and processing.--After seedlings had been lifted, soil from each two pots of each treatment were pooled into two composite samples per treatment. Soil of the composite samples was thoroughly mixed and passed through a 2-mm sieve. Subsamples of the sieved soil were then taken for determination of pH (see above), moisture, ammonium nitrogen, and nitrate nitrogen.

Chemical analysis of foliage.--Moisture content of the needles was determined by drying to constant weight at 65°C. Needles for determination of nitrogen fractions were extracted in a homogenizer with ethanol at a final concentration of 70 percent, and homogenate was centrifuged. The clear solution containing the alcohol-soluble components was extracted with chloroform, and the organic layer containing the lipids and chlorophylls was separated and discarded. Remaining aqueous solution was filtered and completed to volume with distilled water. The aqueous solution was used to determine total soluble N by the standard micro-Kjeldahl procedure, ammonium and nitrate nitrogen according to Bremner (1965) and amide N by the method of Pucher et al. (1935).

Total N (including nitrate) in the ovendry needles was determined by the standard micro-Kjeldahl procedure.

The chlorophylls (a and b) were extracted from the fresh needles with 80-percent acetone. Optical densities of the extracts were measured at 663 and 645 nm in a spectrophotometer, and contents were computed by Arnon's (1949) equations derived from MacKinney's (1941) absorbancy index values.

Minerals were determined in foliage of seedlings from the second harvest only. Analyses were on the dry needles or on solutions of the tissue's ash as follows: P by the molybdenum blue technique (Chapman and Pratt 1961); total S by a turbidimetric method (Butters and Chenery 1959); and K, Ca, Mg, Mn, Fe, Zn, and Cu by standard atomic absorption spectrophotometric techniques (Perkin-Elmer Corporation 1976).

Soil analyses.--Moisture was determined by drying the fresh samples to constant weight at 105°C. Fresh soil samples were extracted with 2N KCl. Ammonium and nitrate nitrogen in the extracts were determined by semimicro-Kjeldahl procedure and steam distillation as described by Bremner (1965).

Statistical analyses.--Data were subjected to analysis of variance, after arc-sine transformation when necessary, and means were compared according to Tukey's test. Correlation coefficients (r) between some variables were also calculated (Snedecor 1961).

RESULTS

In both harvests, trends of measured parameters for the low and high rates of fertilizer application were similar. For simplicity, therefore, we will present only the data pertaining to the low application rate (224 kg N/ha), the rate most commonly used for forest fertilization in the Pacific Northwest. Also, in presenting the data, we will used the 5-percent probability level ($P < 0.05$) to judge statistical significance of differences among treatments.

Soil pH.--Changes in soil pH after treatment are shown in table 1. In the first two pH measurements, 10 and 20 days after treatment, fertilizers varied greatly in their effect on soil reaction. Urea, urea plus N-Serve, urea-ammonium polyphosphate, and urea-ammonium sulfate significantly increased the pH; all other fertilizers also affected pH, but values were not statistically different from pH of the untreated control. By June 30, all treatments were significantly different from the control--pH was higher with urea plus N-Serve and lower with remaining treatments. Subsequently, through the first and second harvests, soil of all treatments became lower in pH than that of the control. In August, however, only seven treatments varied significantly from the control; by the following January, only the ammonium sulfate treatment was significantly different.

Soil ammonium and nitrate nitrogen.--After the first harvest, ammonium and nitrate N in soil varied significantly among treatments, and the untreated soil contained the lowest levels (table 2). The two treatments containing N-Serve resulted in the highest ammonium concentrations, indicating effectiveness of the compound as a nitrification inhibitor. All ammonium- and urea-containing fertilizers were nitrified in the soil, and, except for the urea plus N-Serve treatment, levels of nitrates exceeded those of ammonium.

Table 1--Effect of nitrogen fertilizers on soil pH[1]

Treatment	Measurement date				
	May 2, 1977	May 12, 1977	June 30, 1977	August 1, 1977	January 3, 1978
Untreated control	6.00 def	5.98 cde	6.00 b	5.92 a	5.58 a
Ammonium nitrate	5.75 ef	5.20 e	4.90 c-f	4.96 bc	4.95 ab
Ammonium sulfate	5.44 f	5.28 de	4.60 efg	5.20 abc	4.58 b
Ammonium sulfate + N-Serve[2]	5.55 ef	5.45 de	5.35 c	4.86 bc	4.65 ab
Ammonium sulfate + calcium sulfate	5.58 ef	5.45 de	4.70 d-g	4.75 c	4.78 ab
Calcium nitrate	5.55 ef	5.43 de	5.30 cd	5.12 bc	5.40 ab
Sulfur-coated urea	6.46 cde	6.33 bcd	5.05 cde	5.42 abc	5.55 a
Urea	8.00 a	7.60 a	4.85 c-f	5.36 abc	5.20 ab
Urea + N-Serve[2]	8.10 a	7.33 ab	6.85 a	5.50 ab	5.40 ab
Urea-ammonium sulfate	7.35 abc	7.60 a	4.65 efg	5.02 bc	5.32 ab
Urea + calcium sulfate	6.74 bcd	6.30 bcd	5.15 cde	5.00 bc	5.25 ab
Urea-gypsum	6.75 bcd	6.75 abc	4.40 fg	5.05 bc	5.40 ab
Urea-ammonium polyphosphate	7.69 ab	7.23 ab	4.20 g	4.92 bc	5.45 ab

[1]Values are averages of 2 measurements per treatment. Values in the same vertical column followed by the same letter(s) are not statistically different ($P < 0.05$).

[2]N-Serve is a nitrification inhibitor. Active ingredient is 2-chloro-6(trichloromethyl)pyridine.

By the second harvest, ammonium levels had decreased with all fertilizers because of nitrification and uptake by the seedlings; however, ammonium was still relatively high in soils treated with fertilizers containing N-Serve. With most fertilizers, nitrates were generally lower than in August primarily because of uptake by plants, but in all treatments, levels were still higher than those of ammonium.

Table 2--Effect of nitrogen fertilization on soil ammonium and nitrate nitrogen[1]

Treatment	1st harvest		2d harvest	
	Ammonium nitrogen	Nitrate nitrogen	Ammonium nitrogen	Nitrate nitrogen
		Parts per million		
Untreated control	0.4 e	0.6 d	0.4 b	0.7 e
Ammonium nitrate	3.4 d	33.2 ab	.4 b	36.7 a
Ammonium sulfate	6.2 bc	26.2 ab	.3 b	20.0 abc
Ammonium sulfate + N-Serve[2]	18.2 a	25.8 ab	4.6 a	25.8 ab
Ammonium sulfate + calcium sulfate	4.1 cd	31.6 ab	.6 b	27.6 ab
Calcium nitrate	.9 e	38.3 a	.4 b	33.4 a
Sulfur-coated urea	.9 e	18.0 b	.7 b	5.9 de
Urea	.7 e	15.6 bc	.3 b	7.6 cd
Urea + N-Serve[2]	9.3 b	5.4 cd	2.0 ab	6.2 de
Urea-ammonium sulfate	.9 e	25.4 ab	.3 b	18.2 a-d
Urea + calcium sulfate	1.3 e	27.4 ab	.4 b	10.0 cd
Urea-gypsum	.7 e	16.2 bc	.6 b	6.6 de
Urea-ammonium polyphosphate	.8 e	26.7 ab	.6 b	14.3 bcd

[1]Values are averages of 2 composite soil samples each. Values in the same vertical column followed by the same letter(s) are not statistically different ($P < 0.05$).

[2]N-Serve is a nitrification inhibitor. Active ingredient is 2-chloro-6(trichloromethyl)pyridine.

Growth characteristics.--Dry weight of seedling shoots from the first harvest ranged from 23.5 g for sulfur-coated urea to 48.8 g for ammonium nitrate (table 3). Second-harvest plants varied from 26.1 g for the control to 58.9 g for the urea-ammonium sulfate. In both harvests, however, there were no significant differences among treatments because of large variations within treatments.

Height growth of seedlings of the first harvest ranged from 14.6 percent for ammonium sulfate plus calcium sulfate and urea-ammonium sulfate to 21.4 percent for urea plus N-Serve; it did not vary significantly among treatments. Percent height growth in the second harvest, however, was significantly higher for urea plus N-Serve (53.9 percent) and sulfur-coated urea (49.3 percent) than for the control seedlings (13.8 percent).

Table 3--Growth characteristics of western hemlock seedlings[1]

Treatment	1st harvest			2d harvest		
	Shoot dry weight	Height growth	Diameter growth	Shoot dry weight	Height growth	Diameter growth
	Grams	- - - Percent - - -		Grams	- - - Percent - - -	
Untreated control	30.2 a	16.9 a	5.0 a	26.1 a	13.8 b	7.8 b
Ammonium nitrate	48.8 a	20.0 a	6.7 a	39.8 a	31.5 ab	26.9 ab
Ammonium sulfate	35.0 a	20.7 a	8.6 a	53.8 a	32.4 ab	28.1 ab
Ammonium sulfate + N-Serve[2]	40.0 a	17.4 a	3.1 a	41.6 a	35.2 ab	30.1 ab
Ammonium sulfate + calcium sulfate	42.5 a	14.6 a	4.3 a	46.8 a	34.7 ab	25.0 ab
Calcium nitrate	40.2 a	14.8 a	3.5 a	57.1 a	33.3 ab	25.7 ab
Sulfur-coated urea	23.5 a	18.2 a	10.5 a	48.5 a	49.3 a	58.3 a
Urea	40.2 a	17.4 a	2.4 a	50.8 a	33.3 ab	24.9 ab
Urea + N-Serve[2]	28.2 a	21.4 a	9.9 a	51.2 a	53.9 a	31.2 ab
Urea-ammonium sulfate	40.8 a	14.6 a	24.6 a	58.9 a	46.6 ab	26.9 ab
Urea + calcium sulfate	34.0 a	17.3 a	7.7 a	55.1 a	20.4 ab	23.2 b
Urea-gypsum	39.8 a	15.6 a	10.4 a	51.0 a	29.1 ab	35.1 ab
Urea-ammonium polyphosphate	29.8 a	18.8 a	9.5 a	43.1 a	32.7 ab	18.6 b

[1] Values are averages of 4 seedlings each. Values in the same verticle column followed by the same letter(s) are not statistically different ($P < 0.05$).

[2] N-Serve is a nitrification inhibitor. Active ingredient is 2-chloro-6(trichloromethyl)pyridine.

Diameter growth of seedlings did not vary significantly among treatments of the first harvest; it ranged from 2.4 percent for urea to 24.6 percent for urea-ammonium sulfate. In the second harvest, sulfur-coated urea produced diameter growth (58.3 percent) significantly higher than that of control seedlings (7.8 percent) and of seedlings treated with urea plus calcium sulfate (23.2 percent) and urea-ammonium polyphosphate (18.6 percent).

Foliar nitrogen.--Total N of the needles from the first harvest varied little among fertilizer treatments; it averaged 1.50 percent and was significantly higher than levels in the control seedlings at 0.58 percent (table 4). By the second harvest, average total N for the fertilizer treatments (1.32 percent) was somewhat lower than before--probably because of dilution by growth; total N was still significantly higher in all treated seedlings than in the control. Also, total N content of the needles was significantly correlated with nitrate N of the soil in the first ($r=0.75$) and second ($r=0.48$) harvests.

Table 4--Concentrations of different nitrogen fractions in foliage of western hemlock seedlings[1/]

Treatment	1st harvest					2d harvest				
	Total nitrogen	Ammonium nitrogen	Nitrate nitrogen	Amide nitrogen	Total soluble nitrogen	Total nitrogen	Ammonium nitrogen	Nitrate nitrogen	Amide nitrogen	Total soluble nitrogen
	Percent	- - Parts per million - -			Percent	Percent	- - Parts per million - -			Percent
Untreated control	0.58 b	11 f	18 a	49 b	0.04 f	0.58 b	16 ab	14 b	39 a	0.04 c
Ammonium nitrate	1.61 a	162 a	6 a	69 ab	.26 a	1.42 a	22 ab	22 ab	61 a	.12 a
Ammonium sulfate	1.53 a	108 d	9 a	76 ab	.14 de	1.39 a	13 b	25 a	67 a	.06 c
Ammonium sulfate + N-Serve[2/]	1.48 a	146 ab	24 a	123 ab	.12 e	1.41 a	19 ab	25 a	58 a	.08 abc
Ammonium sulfate + calcium sulfate	1.56 a	140 abc	15 a	113 ab	.17 cd	1.34 a	18 ab	16 ab	53 a	.04 c
Calcium nitrate	1.55 a	118 bcd	23 a	156 ab	.22 ab	1.22 a	20 ab	14 ab	45 a	.08 abc
Sulfur-coated urea	1.39 a	158 a	27 a	107 ab	.14 de	1.22 a	15 ab	19 ab	39 a	.06 c
Urea	1.56 a	140 abc	20 a	129 ab	.21 b	1.34 a	15 ab	23 ab	60 a	.08 abc
Urea + N-Serve[2/]	1.34 a	123 bcd	47 a	125 ab	.12 e	1.32 a	15 ab	19 ab	51 a	.06 c
Urea-ammonium sulfate	1.44 a	109 d	41 a	168 a	.14 de	1.18 a	19 ab	17 ab	37 a	.07 bc
Urea + calcium sulfate	1.50 a	69 e	23 a	115 ab	.13 e	1.30 a	23 ab	17 ab	54 a	.07 bc
Urea-gypsum	1.42 a	110 cd	11 a	67 ab	.12 e	1.24 a	17 ab	21 ab	59 a	.07 bc
Urea-ammonium polyphosphate	1.57 a	165 a	34 a	133 ab	.18 bc	1.41 a	25 a	16 ab	59 a	.08 abc

[1/] Values are averages of 2 composite samples each. Values in the same vertical column followed by the same letter(s) are not statistically different ($P < 0.05$).

[2/] N-Serve is a nitrification inhibitor. Active ingredient is 2-chloro-6(trichloromethyl)pyridine.

Ammonium N in the foliage varied significantly among treatments in the first harvest. Levels were lowest in the control seedlings (11 p/m) and highest in seedlings treated with urea-ammonium polyphosphate (165 p/m), and concentrations were significantly correlated with nitrate N of the soil (r=0.48). Levels decreased greatly by the second harvest; they ranged from 13 to 25 p/m and were significantly higher with urea-ammonium polyphosphate than with ammonium sulfate.

Foliage of the first harvest contained 6 to 47 p/m nitrate N, but there were no significant differences among treatments. In the second harvest, however, there were significantly higher nitrate N levels with the ammonium sulfate and ammonium sulfate plus N-Serve treatments than with the control; foliage of remaining treatments contained similar levels of nitrate N.

Average amide N was much higher in the first (110 p/m) than in the second (52 p/m) harvest. Levels of the first harvest were significantly higher with urea-ammonium sulfate than with the control. Amide N content (37 to 67 p/m), however, did not vary significantly among treatments of the second harvest.

In the first harvest, total soluble N varied significantly among treatments, and the levels in foliage of all fertilized seedlings were significantly higher than in the control trees. Similarly, there were significant differences among treatments in the second harvest, but levels of total soluble N were much lower than before. Concentrations of total soluble N in the needles were significantly correlated with nitrate N of the soil in both the first (r=0.70) and second (r=0.52) harvests.

The chlorophylls.--In the first harvest, all fertilizers significantly increased levels of chlorophyll 'a' and total chlorophyll in the needles over those in foliage of control plants (table 5). Levels of chlorophyll 'b' were also lowest in seedlings from the control, ammonium sulfate, and urea plus N-Serve treatments. Average ratio of chlorophyll 'a' to chlorophyll 'b' was 2.37.

By the second harvest, the control seedlings still contained the lowest concentrations of chlorophyll 'a', chlorophyll 'b', and total chlorophyll. Levels of chlorophyll 'b' in the control seedlings, however, did not vary significantly from levels in foliage from the ammonium sulfate plus N-Serve and calcium nitrate treatments. Also, concentrations of total chlorophyll were similar for the control and calcium nitrate treatments. Average levels of the chlorophylls decreased somewhat in the second harvest, probably as a result of dilution by growth; but average ratio of chlorophyll 'a' to chlorophyll 'b' did not change much (2.02). Total chlorophyll content was significantly correlated with total N in the needles in both the first (r=0.91) and second (r=0.85) harvests.

Table 5--Levels of chlorophyll and chlorophyll ratios in foliage of western hemlock seedlings[1]

Treatment	1st harvest				2d harvest			
	Chlorophyll 'a'	Chlorophyll 'b'	Total chlorophyll	Chlorophyll 'a'/chlorophyll 'b'	Chlorophyll 'a'	Chlorophyll 'b'	Total chlorophyll	Chlorophyll 'a'/chlorophyll 'b'
	Milligrams per gram of dry tissue							
Untreated control	1.12 b	0.54 b	1.67 b	2.06	1.44 c	0.88 b	2.31 c	1.46
Ammonium nitrate	3.62 a	1.53 a	5.15 a	2.36	2.82 ab	1.35 a	4.16 ab	2.08
Ammonium sulfate	2.84 a	1.11 ab	3.96 a	2.56	2.98 ab	1.43 a	4.40 ab	2.08
Ammonium sulfate + N-Serve[2]	3.93 a	1.72 a	5.64 a	2.29	2.72 ab	1.28 ab	4.00 ab	2.12
Ammonium sulfate + calcium sulfate	3.48 a	1.42 a	4.90 a	2.44	2.84 ab	1.35 a	4.20 ab	2.11
Calcium nitrate	3.50 a	1.50 a	5.00 a	2.34	2.20 b	1.16 ab	3.37 bc	1.91
Sulfur-coated urea	2.96 a	1.28 a	4.24 a	2.33	2.68 ab	1.33 a	4.01 ab	2.02
Urea	3.54 a	1.50 a	5.05 a	2.36	2.98 ab	1.43 a	4.41 ab	2.08
Urea + N-Serve[2]	2.94 a	1.17 ab	4.11 a	2.52	3.10 a	1.48 a	4.58 ab	2.08
Urea-ammonium sulfate	3.05 a	1.30 a	4.34 a	2.36	2.73 ab	1.38 a	4.10 ab	1.98
Urea + calcium sulfate	3.36 a	1.44 a	4.79 a	2.36	2.93 ab	1.42 a	4.34 ab	2.08
Urea-gypsum	3.40 a	1.46 a	4.86 a	2.34	3.18 a	1.52 a	4.70 a	2.08
Urea-ammonium polyphosphate	3.38 a	1.42 a	4.80 a	2.46	3.13 a	1.45 a	4.58 ab	2.16

1/Values are averages of 2 composite samples each. Values in the same vertical column followed by the same letter(s) are not statistically different ($P < 0.05$).

2/N-Serve is a nitrification inhibitor. Active ingredient is 2-chloro-6(trichloromethyl)pyridine.

Macroelements other than N.--Concentration of P was significantly higher in the untreated seedlings than in foliage from all other treatments except sulfur-coated urea (table 6). Dilution by growth was probably responsible for this result.

Levels of K, Mg, and S in the foliage varied from 0.66 to 0.83 percent, 0.12 to 0.18 percent, and 0.10 to 0.12 percent, respectively. There were, however, no significant differences among treatments.

Calcium concentration was significantly higher in the control than in seedlings of all other treatments. Again, as with P, this result was probably due to dilution by growth.

Seedlings from fertilizer treatments containing P, Ca, or S were not significantly higher in concentrations of these elements than seedlings from other treatments. Apparently the untreated soil was sufficient in these elements.

Micronutrients.--Concentrations of the four microelements determined varied significantly among treatments (table 6). Highest and lowest Mn levels were in seedlings of the control (696 p/m) and sulfur-coated urea (249 p/m) treatments. Fe levels in the foliage were highest in the control (112 p/m) and lowest in seedlings treated with ammonium sulfate plus calcium sulfate (60 p/m). Fe/Mn ratios ranged from 0.10 to 0.29, but high Mn levels were not associated with reduced concentrations of Fe as was expected.

Zinc levels were significantly lower in foliage from seedlings of the control (8 p/m), urea-gypsum (10 p/m), and sulfur-coated urea (11 p/m) treatments than in foliage from the urea plus calcium sulfate seedlings (33 p/m). Copper concentrations, on the other hand, were lowest and highest in foliage from seedlings of the urea-gypsum (0.1 p/m) and urea (3.0 p/m) treatments.

Table 6--Levels of macronutrients and micronutrients in foliage of western hemlock seedlings, 2d harvest[1]

Treatment	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu
	Percent					Parts per million			
Untreated control	0.22 a	0.72 a	0.61 a	0.18 a	0.10 a	696 a	112 a	8 b	0.2 ab
Ammonium nitrate	.12 b	.74 a	.38 b	.13 a	.10 a	436 a-d	77 ab	15 ab	1.2 ab
Ammonium sulfate	.14 b	.83 a	.37 b	.14 a	.12 a	647 ab	69 ab	13 ab	2.0 ab
Ammonium sulfate + N-Serve[2]	.14 b	.75 a	.33 b	.14 a	.11 a	556 abc	82 ab	12 ab	2.0 ab
Ammonium sulfate + calcium sulfate	.12 b	.77 a	.36 b	.14 a	.12 a	590 abc	60 b	12 ab	.8 ab
Calcium nitrate	.11 b	.67 a	.40 b	.12 a	.10 a	325 cd	65 ab	17 ab	2.0 ab
Sulfur-coated urea	.16 ab	.73 a	.37 b	.14 a	.10 a	249 d	62 ab	11 b	.5 ab
Urea	.14 b	.77 a	.36 b	.14 a	.10 a	368 bcd	72 ab	16 ab	3.0 a
Urea + N-Serve[2]	.15 b	.80 a	.34 b	.14 a	.10 a	254 d	75 ab	13 ab	1.0 ab
Urea-ammonium sulfate	.12 b	.68 a	.34 b	.12 a	.10 a	330 cd	72 ab	19 ab	.8 ab
Urea + calcium sulfate	.14 b	.73 a	.40 b	.14 a	.12 a	386 a-d	88 ab	33 a	1.0 ab
Urea-gypsum	.14 b	.78 a	.30 b	.12 a	.10 a	311 cd	69 ab	10 b	.1 b
Urea-ammonium polyphosphate	.13 b	.66 a	.37 b	.12 a	.10 a	430 a-d	67 ab	13 ab	.8 ab

[1] Values are averages of 2 composite samples each. Values in the same vertical column followed by the same letter(s) are not statistically different ($P < 0.05$).

[2] N-Serve is a nitrification inhibitor. Active ingredient is 2-chloro-6(trichloromethyl)pyridine.

DISCUSSION AND CONCLUSIONS

The different sources of N fertilizers affected soil pH, soil ammonium- and nitrate-N, seedling growth, and foliar chemical composition of the treated trees. For most parameters measured, however, there was much variability within treatments, indicating the need for more replication in future studies.

All fertilizers changed soil pH; initially pH was substantially increased with urea and some of the urea-containing N sources. Such effects were only temporary, and with one exception, pH of soil from fertilizer treatments was not significantly different from that of the untreated soil by the final harvest in January.

Fertilization increased ammonium N which was subsequently nitrified. N-Serve proved to be an effective nitrification inhibitor, but the compound should be evaluated further, especially under field conditions, before it can be recommended for use in the forest.

All fertilizer N sources tested increased seedling growth over that of the control, although most differences between fertilized and unfertilized trees were not significant. More important, there were only small differences among fertilizers in their effect on seedling growth. This indicates that western hemlock can absorb and utilize N from all fertilizers tested. Urea plus N-Serve and sulfur-coated urea, however, appear more promising than other N fertilizer sources.

Total N in the foliage increased substantially after fertilization, and concentrations were correlated with nitrate N of the soil. Foliage from the different fertilization treatments contained similar levels of total N, indicating that N from all fertilizers was equally available to the test seedlings. Ammonium-, nitrate-, and amide-N varied significantly among treatments. Levels of each of these N fractions were always small, however, and concentrations of total soluble N never exceeded 0.26 percent. Most of the N absorbed, therefore, was incorporated as proteins in the treated plants.

Fertilization increased the chlorophyll content of foliage. Average ratio of chlorophyll 'a' to chlorophyll 'b', a little over two, is similar to that found in *Pinus* spp. (Kramer and Kozlowski 1960). Total chlorophyll content was significantly correlated with total N in the needles. This is not surprising since N is a part of the chlorophyll molecule. Also, this correlation agrees with results obtained earlier in our laboratory with foliage from natural stands of western hemlock[3] and with recent findings in other conifers by Heinze and Fiedler (1976).

In general, foliar concentrations of the macronutrients and microelements were either depressed or not affected by fertilizer. This was probably caused by dilution effects resulting from increased growth from application of N and supplements with essential elements other than N which the test seedlings received just before treatment.

Results from this study suggest that the source of N in the fertilizer does not appear to be responsible for the reported variability in response of natural stands of western hemlock to N fertilization. It is obvious, however, that conditions under which this study was carried out vary greatly from those commonly found in the forest. Accordingly, we recommend field tests with a limited number of fertilizers before the source of N can be completely ruled out as a factor affecting response of western hemlock to N fertilization.

[3] Radwan, M. A., and D. S. DeBell. Unpublished data on file at the Forestry Sciences Laboratory, Olympia, Wash.

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Twelve different nitrogen (N) fertilizer treatments were tested on potted western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) seedlings. Fertilizers affected soil N and pH, and growth and foliar chemical composition of seedlings. Urea plus N-Serve and sulfur-coated urea appear more promising for promoting growth than other fertilizers tested. Results, however, do not explain reported variability in response of hemlock stands to N fertilization.

Keywords: Nitrogen fertilizer response, seedling growth, western hemlock, *Tsuga heterophylla*.

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